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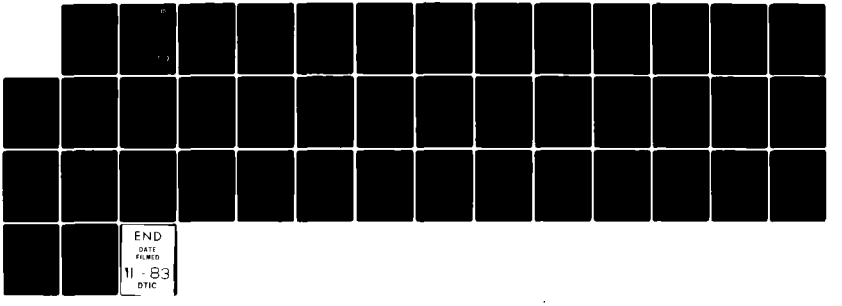

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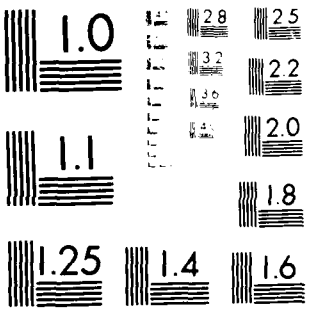

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April 1983

US Army Corps
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Cold Regions Research &
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Optimization model for land treatment planning, design and operation

Part III. Model description and user's guide

J.A. Baron and D.R. Lynch

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A nonlinear optimization model applicable to slow-rate land treatment systems in cool, humid regions is described. The model prescribes optimal design variables as well as an operating schedule for a facility comprising a storage lagoon with bypass and a single-crop irrigation system. The optimization is achieved by use of generalized, commercially available software that embodies the reduced gradient method. The model equations are presented. The computational structure as implemented on the CRREL Prime System is described, with instructions for use. A sample problem illustrates model application, and a program listing is appended.

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PREFACE

This report was prepared by Jaclyn A. Baron, graduate assistant, and Daniel R. Lynch, Assistant Professor, Thayer School of Engineering, Dartmouth College. The report is Part III of a three-part series, "Optimization Model for Land Treatment Planning, Design and Operation." Part I of the series (Baron et al. 1983a) provides background information and a review of the land treatment optimization literature. A case study illustrating methods, results, and sensitivity analysis is presented in Part II (Baron et al. 1983b). Details of the principal mathematical model and its realization in computer form (LTMOD) are presented in this part.

This work has been supported by the U.S. Army Corps of Engineers under CWIS 31732, Land Treatment Management and Operation. This report was technically reviewed by Dr. A.O. Converse and Dr. T.J. Adler of the Thayer School of Engineering, Dartmouth College.

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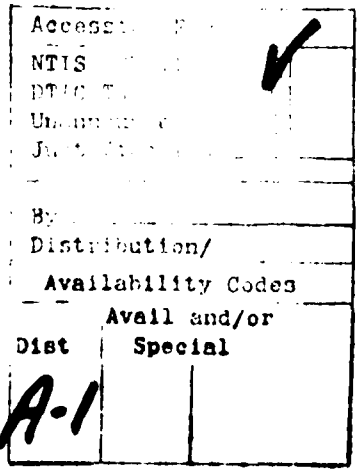

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OPTIMIZATION MODEL FOR LAND TREATMENT PLANNING, DESIGN AND OPERATION
PART III. MODEL DESCRIPTION AND USER'S GUIDE

Jaclyn A. Baron and Daniel R. Lynch

INTRODUCTION

LTMOD is a Fortran-coded model that generates optimal combinations of design and monthly operating parameters for slow-rate land treatment of wastewater systems with a given quantity of incoming effluent. It is a generalized formulation of the models developed in Evaluation of Design and Operating Options for Slow-Rate Land Treatment Systems in Cool/Humid Areas (Baron 1981).

LTMOD consists of a main program, which coordinates several input and output files, and a subroutine containing a set of equations representing the physical relationships, the groundwater quality constraints, and the objective function of the land treatment system. These equations are coupled with additional subroutines comprising a generalized reduced-gradient, nonlinear programming algorithm. User input is required for 1) parameters of the LTMOD equations--wastewater influx, physical constants, desired environmental quality, and design objective for the site, and 2) properties of the optimization procedure, including constraint types, variable bounds, an initial solution point, and various tolerances within the algorithm. Together, these two input types define the physical system, the operating options, and the feasible solution space.

This report defines the model capabilities and underlying assumptions, presents an overview of the model structure, details the LTMOD equations and their parameters, discusses the procedure for running the model, and includes a sample problem and results. Input for the optimization procedure is described only when it is important that it be consistent with the LTMOD equations. Additional options and detailed formatting specifications for input for the optimization procedure are in the GRG2 User's Guide (Lasdon et al. 1978), with which this manual should be used.

MODEL CAPABILITIES AND UNDERLYING ASSUMPTIONS

LTMOD recognizes the dual nature of the land treatment process whereby nitrogen in the effluent is removed by biological, physical and chemical processes in both the storage facility and in the soil-crop system. The

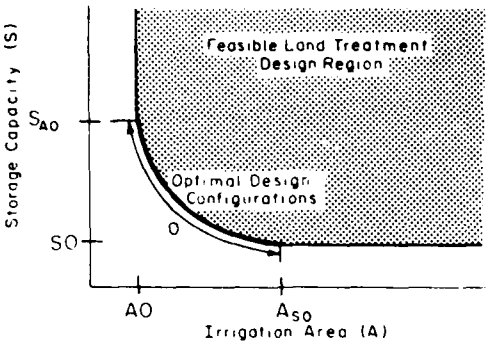

Figure 1. Land treatment design alternatives.

resultant design tradeoff between storage capacity and irrigation area is the fundamental issue behind the model. A general representation of the full set of design alternatives is shown in Figure 1. The feasible design options are bounded by 1) AO, the minimum area to which effluent can be applied to avoid ponding (based on the drainage properties of the site), 2) SO, the minimum storage capacity required to hold effluent during the months when application is not permitted, and 3) combinations of irrigation area $\geq$ AO and storage capacity $\geq$ SO that are just sufficient to meet the groundwater quality constraints. The lowest cost designs lie along or at the ends of segment 0, at the edge of the feasible region. Based on the potential for renovation of the effluent nitrogen in storage and on the land and the permissible nitrogen concentration in the groundwater underlying the site, LTMOD may be used to satisfy one of three design objectives:

1) Find the minimum required effluent storage facility capacity S that is associated with a given irrigation area A where A $\geq$ AO.
2) Find the minimum required irrigation area A that is associated with a given effluent storage facility capacity S where S $\geq$ SO.
3) Find the minimum required irrigation area AO and the minimum effluent storage facility capacity S_{AO} associated with this area.

The quantity of nitrogen removed from the effluent in storage and on the land (and in the system as a whole) depends on dynamic processes and thus on the operating characteristics of the site. Operating decision variables include the volume of effluent stored, the volume of effluent

applied to the irrigation area from storage, and the volume of effluent that bypasses the storage facility for each month throughout one year of operation. Additional system operating properties, which follow from these controllable operating decisions, include the drainage from the site, the nitrogen concentration in the percolate, the nitrogen concentration in storage, and crop nitrogen uptake for each month.

The LTMOD equations explicitly or implicitly include certain assumptions that delineate the type and properties of the system to which the model may be applied. Specifically, it must be a single-crop system in a cool and/or humid area, and the groundwater nitrogen concentration must be the limiting environmental concern.

The model assumes that a single crop is grown on the entire irrigated site, that the cropped area is equal throughout its growing season, and that the entire area is evenly irrigated. The planting and harvesting regime is exogenously fixed.

The model is for a cool and/or humid area. The mass balances by which the drainage from the site is calculated are independent for each month and do not provide for changes in the soil moisture content. It is assumed that the soil is always kept at or near field capacity. It follows that sufficient soil moisture is available to the crop at all times to avoid water deficit and stress. Crop moisture uptake is assumed to be independent of effluent application and to equal the potential evapotranspiration rate in each month.

Groundwater nitrogen concentration is assumed to be the limiting environmental consideration. Nitrogen is the only system contaminant explicitly modeled. The concentration of nitrogen in the percolate from the site may be constrained on an annual and/or monthly basis. Nitrogen removal in the storage facility is represented by an overall monthly first-order reaction constant. Monthly crop uptake is represented by exponential functions of the nitrogen available to the crop. The monthly nitrogen mass balances are interdependent and allow for the soil storage and release of applied nitrogen in succeeding months that has been observed, especially during winter application of effluent at experimental sites. This is accomplished by estimating the percentage of the nitrogen in the soil system that is leached in each month (not including native soil nitrogen, which is assumed to remain constant).

OVERVIEW OF MODEL STRUCTURE

The model consists of the sections shown in Table 1. Figure 2 shows the interactions between the model components. The main program allocates memory and numbers the input and output files. It calls subroutine GRG, which is part of the GRG2 file, where the optimizing process occurs. The INPUT and DEFINE files are read in the DATAIN subroutine and GCOMP is called upon as needed. The PARAM file is read by GCOMP on the initial iteration. The output is sent to the file specified for this purpose by various subroutines in the GRG2 program.

The LTMOD, GRG2 and DEFINE files must be available and accessible on the data processing system. The GRG2 file, the DEFINE file and the GCOMP portion of the LTMOD file are used as they are; the MAIN program may require modifications pertaining to the allocated memory and file numbering, depending on the type of system for which the model is used.

Table 1. LTMOD files.

File Name	Contents
LTMOD	Main program and subroutine GCOMP (land treatment equations).
GRG2	Nonlinear optimization algorithm subroutines.
DEFINE	Names of LTMOD functions and variables for labeling output.
PARAM	Parameters of LTMOD equations.
INPUT	Variable and function types, variable bounds and options for optimization procedure.
OUTPUT	Output file of intermediate information and results.

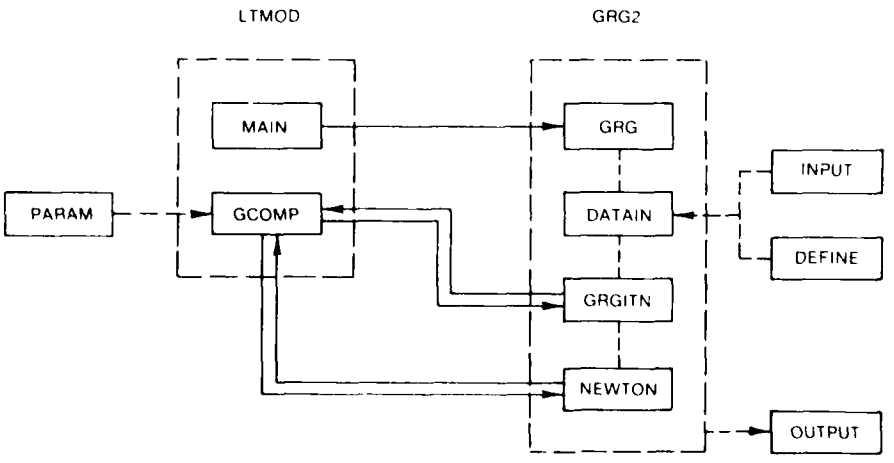

Figure 2. Model components and their interactions.

The INPUT and PARAM files are supplied by the user. All files may be arbitrarily named.

LTMOD FILE

The generalized land treatment formulation contained in subroutine GCOMP in the LTMOD file consists of 85 functions comprising the system constraints, an objective function, and 7 calculations of auxiliary system properties that are not included in the optimization process. The functions include 85 decision variables and 160 parameters. GCOMP need not be modified by the user; however, an understanding of the land treatment equations is necessary to develop the user-supplied PARAM and INPUT files and to interpret the model results. A schematic of the system, including the major variables and parameters, is shown in Figure 3. Below, the 93 individual equations are described, using the equation numbering scheme G(1) through G(93) that is used in the GCOMP code.

Note that continuous multiyear operation of the system is assumed, and thus all variables defined at the end of month 12 are required to be identical to those at the beginning of month 1. Any occurrence of the subscript 0 implies the subscript 12.

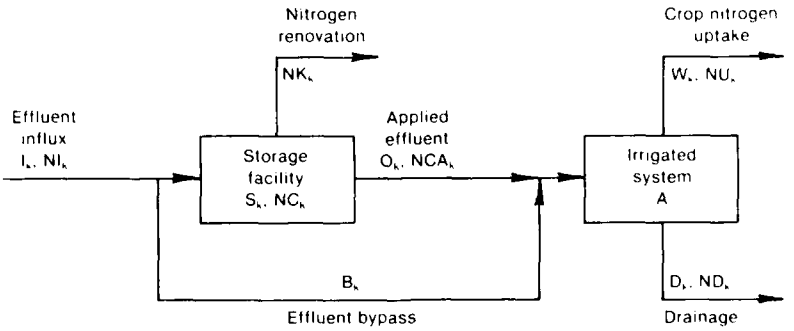

Figure 3. Simplified schematic of a land treatment system. Variables are defined in the text.

LTMOD Constraints

Equations G(1) - G(12) represent the monthly mass balance of water in storage:

$$O_k + B_k + S_k - S_{k-1} + (E_k - P_k) \cdot \max(S_1 \ldots S_{12})/DP = I_k \quad (1)$$

where the decision variables are

O_k = volume of effluent applied from storage in month k

B_k = volume of effluent applied which bypasses storage in month k

S_k = storage volume at end of month k

and the parameters are

E_k = evaporation volume in month k per unit area

P_k = precipitation volume in month k per unit area

DP = depth of storage facility (design depth at maximum volume)

I_k = incoming effluent volume in month k.

Equations G(13) - G(24) represent the monthly mass balance of water at the irrigation site:

$$EFF_k \cdot (O_k + B_k) + (P_k - W_k) \cdot A - D_k = 0 \qquad (2)$$

where the decision variables are

O_k = volume of effluent application from storage in month k

B_k = volume of effluent application which bypasses storage in month k

A = irrigation area

D_k = volume of percolate from site in month k

and the parameters are

EFF_k = irrigation efficiency in month k including runoff

P_k = precipitation depth in month k

W_k = crop water uptake in month k (depth).

Equations G(25) - G(36) require that the soil drainage capacity in each month must not be exceeded:

$$MDR_k \cdot A - D_k \geq 0 \qquad (3)$$

where the decision variables are

A = irrigation area

D_k = volume of percolate from site in month k

and the parameter is

MDR_k = soil drainage capacity in month k (depth).

Equations G(37) - G(48) represent the monthly mass balance of nitrogen at the irrigation site:

$$1/FNL_k \cdot (ND_k) - (1 - DeN_k) \cdot [O_k \cdot NCA_k + B_k \cdot NI_k + (1 - FNL_{k-1})/FNL_{k-1} \cdot ND_{k-1}]$$

$$+ A \cdot NU_k = 0 \qquad (4)$$

where NCA_k, the average nitrogen concentration in storage in month k, is approximated as

$$NCA_k = (NC_k \cdot S_k + NC_{k-1} \cdot S_{k-1})/(S_k + S_{k-1}) \quad . \qquad (5)$$

The decision variables are

ND_k = mass of nitrogen leached to groundwater to month k

O_k = volume of effluent application from storage in month k

NC_k = nitrogen concentration in storage at end of month k

S_k = storage volume at end of month k

B_k = volume of effluent application which bypasses storage in month k

A = irrigation area

NU_k = crop nitrogen uptake in month k (mass/area)

and the parameters are

FNL_k = fraction of soil system nitrogen imbalance leached in month k: $ND_k = [FNL_k/(1-FNL_k)] \cdot NSS_k$, where NSS_k is the nitrogen stored in the soil system at the end of month k

$(1-FNL_k)$ = fraction of soil system nitrogen imbalance retained in soil storage at the end of month k

DeN_k = fraction of nitrogen in soil system lost through denitrification and volatilization in month k

NI_k = nitrogen concentration of incoming effluent in month k.

Equations G(49) - G(60) describe the monthly crop uptake of nitrogen, represented as an exponential function of the nitrogen applied. Its basic form is

$$NU_k = CP_k \cdot MNU_k \cdot [1 - EXP(-b/MNU_k)] \qquad (6)$$

where b, the nitrogen available to the crop per unit land area is

$$b = [NI_k \cdot B_k + NCA_k \cdot O_k + (1 - FNL_{k-1})/FNL_{k-1} \cdot ND_{k-1}]/A \quad . \qquad (7)$$

Substitution for NCA_k and rearrangment yields

$$NU_k - CP_k \cdot MNU_k \cdot \left\{1 - EXP\left[\left(\left[- NI_k \cdot B_k - (1 - FNL_{k-1})/FNL_{k-1} \cdot ND_{k-1}\right] \cdot (S_k + S_{k-1}) - O_k \cdot (NC_k \cdot S_k + NC_{k-1} \cdot S_{k-1})\right)/[(S_k + S_{k-1}) \cdot A \cdot MNU_k]\right]\right\} = 0 \quad . \qquad (8)$$

The decision variables are

NU_k = crop nitrogen uptake in month k (mass/area)

B_k = volume of effluent application which bypasses storage in month k

ND_k = mass of nitrogen leached to groundwater in month k

S_k = storage volume at end of month k

O_k = volume of effluent application from storage in month k

NC_k = nitrogen concentration in storage at end of month k

A = irrigation area in month k

and parameters are

MNU_k = maximum crop nitrogen uptake in month k (mass/area)

NI_k = nitrogen concentration of incoming effluent in month k

FNL_k = fraction of soil system nitrogen imbalance leached in month k

CP_k = 1 if crop is grown in month k, = 0 if it is not. CP_k must also be set to zero if crop does not take up nitrogen in a month of growth.

Equations G(61) - G(72) represent the monthly mass balance of nitrogen in storage:

$$NC_k \cdot S_k - NC_{k-1} \cdot S_{k-1} + O_k \cdot NCA_k + NK_k \cdot NCA_k \cdot SA_k + NI_k \cdot B_k = I_k \cdot NI_k \qquad (9)$$

where SA_k, the average storage volume in month k is:

$$SA_k = (S_k + S_{k-1})/2 \quad . \qquad (10)$$

Substituting for NCA_k and SA_k and simplifying terms yields:

$$NC_k \cdot S_k - NC_{k-1} \cdot S_{k-1} + O_k \cdot (NC_k \cdot S_k + NC_{k-1} \cdot S_{k-1})/(S_k + S_{k-1}) + \frac{1}{2} NK_k \cdot (NC_k \cdot S_k + NC_{k-1} \cdot S_{k-1}) + NI_k \cdot B_k = NI_k \cdot I_k \qquad (11)$$

The decision variables are

NC_k = nitrogen concentration in storage at end of month k

S_k = volume of storage at end of month k

O_k = volume of effluent application from storage in month k

B_k = volume of effluent application which bypasses storage in month k

and the parameters are

NK_k = percentage of nitrogen removed in storage in month k

NI_k = nitrogen concentration of incoming effluent in month k

I_k = incoming effluent volume in month k.

Equation G(73) enforces the annual percolate nitrogen concentration constraint.

$$NCQ \cdot \sum_k D_k - \sum_k ND_k \geq 0 \quad . \qquad (12)$$

The decision variables are

D_k = percolate volume from site in month k

ND_k = mass of nitrogen leached to groundwater in month k

and the parameter is

NCQ = maximum permissible annual average nitrogen concentration in the groundwater.

Equations G(74) - G(85) enforce the monthly percolate nitrogen concentration constraint:

$$NCQM \cdot D_k - ND_k \geq 0 \quad . \qquad (13)$$

The decision variables are

D_k = percolate volume from the site in month k

ND_k = mass of nitrogen leached to groundwater in month k

and the parameter is

NCQM = maximum permissible monthly nitrogen concentration in the groundwater in month k.

LTMOD objective function

Equation G(86) states the objective:

$$\text{Minimize } [OA \cdot A + OB \cdot MAX(S_1 \ldots S_{12})] \qquad (14)$$

where the decision variables are

A = irrigation area

S_k = storage volume at the end of month k.

Varying the values of the parameters OA and OB enables a choice of three objectives:

1) To minimize the irrigation area with a given storage capacity, set OA = 1 and OB = 0,

2) To minimize the storage capacity with a given irrigation area, set OA = 0 and OB =1,

3) To minimize the irrigation area based on hydraulic properties of the site and to find the minimum required storage associated with this area, set OA = 1 and OB = fractional value ensuring that the storage term in the objective function is less than the area term at all times in the optimization procedure.

It is essential that the classification and bounds on the storage and area decision variables in the INPUT file (see below) be consistent with the choice of objective.

LTMOD additional calculations

Equations G(87) - G(93) represent auxiliary calculations concerning the system size and the various renovation processes. The mass of nitrogen removed in the storage facility is calculated in G(87):

$$G(87) = \sum_k NK_k \cdot (NC_k \cdot S_k + NC_{k-1} \cdot S_{k-1})/2 \qquad (15)$$

while the percentage of nitrogen removed in storage is calculated in G(88):

$$G(88) = G(87)/\sum_k (NI_k \cdot I_k). \qquad (16)$$

Equations G(89) and G(90) calculate the comparable mass- and percentage-removal figures for the crop:

$$G(89) = A \cdot \sum_k NU_k \qquad (17)$$

$$G(90) = G(89)/\sum_k (NI_k \cdot I_k). \qquad (18)$$

Equation G(91) calculates the total mass of nitrogen removed by the two processes:

$$G(91) = G(87) + G(88) \qquad (19)$$

while G(92) gives the overall nitrogen removal percentage:

$$G(92) = G(91)/\sum_k (NI_k \cdot I_k). \qquad (20)$$

Finally, the maximum weekly wastewater application rate is computed in eq G(93):

$$G(93) = MAX(O_1 \ldots O_{12})/(4.3\ A). \qquad (21)$$

PARAM FILE

The PARAM file contains the parameters for the LTMOD land treatment equations and is supplied and named by the user. A total of 160 parameter values must be specified. The file must consist of 26 lines with 6 values on each and a 27th line with 4 values. The values are input in fields of 10 and are formatted F10.6. They are inserted in the order shown in Table 2.

Table 2. Order of input for parameter values. The GRG2 User's Guide (Lasdon et al. 1978) states that best results are obtained when the absolute values of the problem functions are less than 10^2, so parameters should be scaled accordingly.

Lines	Parameter	
1 and 2	I(12)	Incoming effluent in each month (volume).
3 and 4	P(12)	Precipitation in each month (depth).
5 and 6	E(12)	Evaporation in each month (depth).
7 and 8	W(12)	Crop water uptake (PET) in each month (depth).
9 and 10	MRD(12)	Soil drainage capacity in each month (depth).
11 and 12	NI(12)	Nitrogen concentration of incoming effluent in each month (mass/volume).
13 and 14	NK(12)	Percentage of nitrogen removed in storage in each month.
15 and 16	DeN(12)	Fraction of nitrogen in soil lost through denitrification and volatilization in each month.
17 and 18	CP(12)	Growth/no growth indicator for crop in each month (0.0 or 1.0).
19 and 20	MNU(12)	*Maximum potential crop nitrogen uptake in each month (mass/area).
21 and 22	FNL(12)	+Fraction of nitrogen in soil leached in each month.
23 and 24	NCQM(12)	Maximum permissible nitrogen concentration in percolate in each month (mass/volume).
25 and 26	EFF(12)	Irrigation efficiency in each month.
27	NCQ	Maximum permissible annual average nitrogen concentration in groundwater (mass/volume).
27	OA	Objective function area term coefficient (0.0 or 1.0).
27	OB	Objective function storage term coefficient, $0.0 \leq OB \leq 1.0$.
27	DP	Depth of storage facility.

*If the crop is not grown in month k, MNU_k should be set to some arbitrary positive value to avoid division by zero.

+The fraction of nitrogen leached in each month must be set to a positive value to avoid division by zero.

INPUT FILE

The input file is supplied and named by the user. The file must be consistent with the instructions and format specifications in the GRG2 User's Guide, Section 5. The required parts of this file are:

1) Line 1 (Number of variables and functions).
2) ROWS section (Function type and right-hand sides).
3) BOUNDS section (Variable type and bounds).
4) INITIAL section (Initial values of decision variables).
5) FUNCTION and VARIABLE section titles. (Title lines only, in this order. The remainder of these sections is read from the DEFINE file.)

The user may wish to reduce or expand the level of printout, reduce computation time, or improve performance by activating additional options discussed in the GRG2 User's Guide, Section 5.

The required sections are discussed in detail below. A portion of the data will be identical for any run using the LTMOD model. The user should note which inputs are fixed (indicated with an asterisk) and which depend on the particular application.

Line 1

The number of variables is 85*, and the number of functions is 93*. Neither of these numbers may be modified by the user.

ROWS section

For each of eq G(1) - G(93) the equation type must be specified according to the following letter code:

E indicates an equality constraint,
G indicates a "greater than or equal to" constraint,
O indicates the objective function,
N indicates a constraint that is ignored in the optimization.

Table 3 indicates the proper choice of type code as well as the proper value for the right side of each equation. Only eq G(73)-G(85), which deal with the form of the environmental constraints, require user decisions with respect to equation type. Equation G(73) is set greater than or equal to zero (G) if the nitrogen concentration in the percolate is to be constrained on an average annual basis, and ignored in the optimization procedure (N) if it is not. Likewise, eqs G(74) - G(85) are set greater

Table 3. Function types and right sides for ROWS section of input file.

Function	Type	Right side
G(1)-G(12)	E*	I_k+
G(13)-G(24)	E*	0.0*
G(25)-G(36)	G*	0.0*
G(37)-G(48)	E*	0.0*
G(49)-G(60)	E*	0.0*
G(61)-G(72)	E*	$NI_k \cdot I_k$
G(73)	G or N	0.0*
G(74)-G(85)	G or N	0.0*
G(86)	O*	- *
G(87)-G(93)	N*	- *

*These inputs are fixed.
+I_k = incoming effluent in month k (volume),
NI_k = nitrogen concentration of incoming effluent in month k (mass/volume).

than or equal to zero (G) if the nitrogen concentration in the percolate is to be constrained on a monthly basis, and ignored in the optimization procedure (N) if it is not.

BOUNDS section

The variable types and bounds depend heavily on the particular application. The assignment of variable bounds describes physical constants and constraints of the land treatment system that are not addressed by the system parameters and defines the operating options that may be considered in the search for an optimal solution. It is important that variable bounds be consistent with the system parameters. This section includes definitions of the 85 LTMOD decision variables and some guidance for assigning types and bounds. As in the ROWS section, a letter code signifies the type of bounds on each variable:

- E indicates that the variable is fixed at a given value,
- G indicates that the variable must be greater than or equal to a given value,
- R indicates that the variable is restricted between two given values.

X(1): Irrigation area A. If the objective is to minimize the irrigation area with a given storage capacity (OA = 1, OB = 0) or to minimize the irrigation area based on hydraulic properties of the site and find the minimum required storage associated with this area (OA = 1, OB = fractional

value), then set X(1) greater than or equal to (G) zero. If the objective is to minimize the storage capacity with a given irrigation area (OA = 0, OB =1) then set X(1) as a fixed variable (E) at the area of interest.

X(2)-X(13): Storage volume at the end of each month S_k. The storage volume at the end of each month must be higher than some small positive value to avoid division by zero. If the objective is to minimize the irrigation area with a given storage capacity (OA = 1, OB = 0), then set X(2)-X(13) as restricted variables (R) between the small positive value and the storage capacity of interest. The model solution will always contain at least one storage volume that is equal to this storage capacity.

If the objective is to minimize the storage capacity with a given irrigation area (OA = 0, OB = 1) or to minimize the irrigation area based on hydraulic properties of the site and find the minimum required storage associated with this area (OA = 1, OB = fractional value), then set X(2)-X(13) as greater than or equal to (G) variables with a lower bound of the small positive value.

X(14)-X(25): Monthly effluent application from storage O_k. Monthly effluent applications should be set to be greater than or equal to (G) zero in the months when application is permitted when irrigation capacity is not a concern, and as restricted variables (R) between zero and the irrigation capacity if appropriate. Effluent application is permissible in months when crops are not grown. In months when effluent application is not permitted due to climatic considerations, the effluent application variables should be fixed (E) at zero.

X(26)-X(37): Monthly percolate from site D_k. Monthly percolate variables should be set greater than or equal to (G) zero in all months.

X(38)-X(49): Nitrogen concentration in storage at end of each month NC_k. Nitrogen concentration in storage should be set greater than or equal to (G) zero in all months.

X(50)-X(61): Monthly crop uptake of nitrogen NU_k. Crop uptake of nitrogen can be set greater than or equal to (G) zero in all months. In months when crops are not grown in nitrogen, uptake is fixed at zero by the CP_k parameter.

X(62)-X(73): Monthly quantity of nitrogen leached to the groundwater ND_k. The quantity of nitrogen leached variables should be set greater than or equal to (G) zero in all months.

X(74)-X(85): Monthly effluent application which bypasses storage B_k. If bypassing the storage facility is an operating option, the bypass variables should be restricted (R) between a lower bound of zero and an upper bound of I_k, the incoming effluent volume in each month when application is permitted. If bypassing storage is not a viable option, the bypass variables should be fixed (E) at zero.

INITIAL section

Initial values of the decision variables must be chosen for each model run. The initial solution point need not be feasible; however, if the initial point is poor, a feasible solution may not be reached and either the problem will be declared infeasible or various error messages (size, division by zero) will be generated. LTMOD is particularly sensitive to the relative values of the irrigation area and the effluent storage capacity; it is relatively insensitive to the initialization of the other decision variables as long as they are within reason. If the program does not complete the run, modify the initial irrigation area X(1) when minimizing the area with a given storage capacity, or modify the initial storage volumes X(2)-X(13) when minimizing the storage capacity with a given irrigation area, and try again.

Depending on the initial solution, the global optimum may not be reached for reasons that are discussed in the GRG2 User's Guide (Lasdon et al. 1978). If the final irrigation area or maximum storage volume is less than the initial point, it is a good idea to check that it is indeed the minimum requirement by lowering the initial estimate to below this value and rerunning. Another possible check that the solution is optimal is by comparison; run several cases around the point of interest and check that none of the solutions is out of line.

A reasonable initialization procedure is:

1) Distribute the effluent application X(14)-X(25) evenly over all the months in which it is feasible and set it to zero for the remaining months.
2) Set the drainage volume in each month X(26)-X(37) equal to the effluent application.
3) Calculate the nitrogen leached in each month X(62)-X(73) by multiplying the drainage volume by the maximum permissible nitrogen concentration in the percolate (NCQ or NCQM).

4) Set the nitrogen concentration in storage in each month X(2)-X(13) as half the incoming effluent value.

5) Estimate the crop nitrogen uptake in each month in which it is grown by multiplying the nitrogen concentration in storage by the effluent application and using the crop nitrogen uptake exponential functions.

6) Bypass variables X(74)-X(85) tend, in final solution, to be at their lower bound (zero) or their upper bound (the incoming effluent volume), depending upon the application; it is worthwhile to rerun the model with low and high initial bypasses to ensure that the optimal solution is found.

7) When minimizing the irrigation area associated with a given storage capacity, set the storage in each month X(2)-X(13) at approximately half the maximum. Roughly estimate the hydraulically feasible area by dividing the effluent volume applied each month by an average drainage capacity. Set the initial area X(1) somewhere above this result.

When minimizing the storage capacity associated with a given irrigation area, find the storage capacity required to store the incoming effluent volume during the months when irrigation is not feasible; set the storage volumes X(2)-X(13) somewhere above half of this result.

RUNNING LTMOD ON THE PRIME SYSTEM

Running LTMOD as a segmented run file on a Prime system is straightforward. The LTMOD file may be used with no modification. The allocated memory, PARAMETER MAXMEM, is 20000. The file numbering is:

INPUT	LOGICAL UNIT 5
PARAM	LOGICAL UNIT 7
DEFINE	LOGICAL UNIT 8
OUTPUT	LOGICAL UNIT 6.

The run procedure is as follows:

1) Compile LTMOD and GRG2 files. Either the Fortran IV (FTN) or Fortran 77 (F77) compiler may be used:

F77 LTMOD	or	FTN LTMOD -64V
F77 GRG2 -BIG		FTN GRG2 -64V -BIG.

2) Load Segmented Runfile:

```
SEG             (initialize SEG utility)
lo #LTM         (load runfile name)
lo b-LTMOD      (load compiled LTMOD)
lo b-GRG2       (load compiled GRG2)
li vapplb       (v-mode applications library)
li              (standard Fortran library)
save            (save runfile)
Q               (quit SEG utility and return to Primos command level).
```

The package is now saved for all future runs. To run in foreground, type SEG #LTM (or runfile name) and input the INPUT, PARAM, DEFINE and OUTPUT file names as requested.

A typical background job might look like:

```
JOB user # -HOME 'user # password' -QUEUE LONG
COMO RUNLIST
SEG # LTM
INPUT
PARAM
DEFINE
OUTPUT
LOGOUT
```

Runtime error messages are available by listing the RUNLIST file.

SAMPLE PROBLEM AND RESULTS

Problem statement

The sample system is a hypothetical 10-mgd facility with climatic and crop data typical of central New Hampshire. The incoming effluent volume is evenly distributed over the year (1,151,300 m^3/month). Monthly estimates of precipitation and evaporation at the site are shown in Table 4. A mixed forage crop is grown on the site from early April to mid-November, and its potential evaporation rate is assumed to equal the evaporation rate throughout its growing season. The soil is a sandy loam with a maximum hydraulic loading of 8 in./week (87 cm/month). Irrigation efficiency is 70% and runoff is assumed to be negligible.

The incoming effluent contains 40 mg/L nitrogen. The nitrogen removal in the storage facility is 20% in each month from April through November

Table 4. Climatic data for the sample problem.

Month	Precipitation (cm)	Potential Evaporation (cm)
January	6.9	0.0
February	5.8	0.0
March	6.6	0.0
April	6.6	3.0
May	7.9	7.7
June	8.6	11.2
July	8.9	13.4
August	8.9	11.3
September	8.1	7.6
October	7.9	3.9
November	7.1	0.6
December	6.6	0.0

Table 5. Estimated monthly percentages of seasonal nitrogen uptake for the sample problem.

Month	% Seasonal N Uptake
April	15
May	20
June	15
July	20
August	20
September	10
October	-
November	-

and 10% in the cold months from December through March. The maximum seasonal uptake of the forage is 470 kg/ha under a harvesting regime that includes three cuttings. The percentage of the total seasonal uptake that may be expected in each month with this management schedule is shown in Table 5. Maximum monthly nitrogen uptake values are estimated by multiplying the maximum seasonal uptake by the appropriate percentages. Nitrogen losses by denitrification and volatilization are assumed to be negligible. All nitrogen applied to the irrigated area in the effluent that is not consumed by the crop is assumed to leach in the same month in which it is applied.

The study objective is to find the minimum required irrigation area associated with a storage facility with a 5,500,000-m^3 capacity and 12-ft

(3.66-m) depth to achieve an annual average concentration of nitrogen in the percolate of 10 mg/L. Effluent irrigation is feasible only during the growing season of the forage crop. Bypassing the storage facility is not permitted.

Input and output files

The PARAM file for the problem is shown in Table A1. Two items illustrate the flexibility available to the user:

1) A percentage of the winter precipitation is snow, which melts and percolates through the soil in the spring. In this example, for simplicity, 100% of the winter precipitation is deferred until April when it is assumed to enter the soil system.

2) To model the fact that effluent application is permissible only in the first half of November, the drainage capacity is halved in this month.

The INPUT file for the run is shown in Table A2. The complete OUTPUT file is shown in Table A3. The required irrigation area is 1280 hectares. Refer to the GRG2 User's Guide for further details of the output information.

LITERATURE CITED

Baron, J.A. (1981) Evaluation of design and operating options for slow-rate land treatment systems in cool/humid areas. M.S. thesis, Thayer School of Engineering, Dartmouth College, Hanover, New Hampshire.

Baron, J.A., D.R. Lynch and I.K. Iskandar (1983a) Optimization model for land treatment planning, design and operation. Part I: Background and literature review. CRREL Special Report 83-6.

Baron, J.A., D.R. Lynch and I.K. Iskandar (1983b) Optimization model for land treatment planning, design and operation. Part II: Case study. CRREL Special Report 83-7.

Lasdon, L.S., A.D. Waren and M.W. Ratner (1978) GRG2 User's Guide. School of Business Administration and Department of Mechanical Engineering, University of Texas at Austin; Department of Computer and Information Science, College of Business Administration, Cleveland State University, Cleveland; Department of Systems Engineering, Computer Engineering and Information Sciences, Case Western Reserve University, Cleveland.

APPENDIX A: INPUT AND OUTPUT FOR THE SAMPLE PROBLEM.

Table A1. PARAM File.

11.513	11.513	11.513	11.513	11.513	11.513
11.513	11.513	11.513	11.513	11.513	11.513
0.0	0.0	0.0	0.325	0.079	0.036
0.089	0.089	0.081	0.079	0.071	0.0
0.0	0.0	0.0	0.03	0.077	0.112
0.134	0.133	0.076	0.039	0.006	0.0
0.0	0.0	0.0	0.03	0.077	0.112
0.134	0.113	0.076	0.039	0.006	0.0
0.87	0.87	0.87	0.87	0.87	0.87
0.87	0.87	0.87	0.87	0.435	0.87
0.04	0.04	0.04	0.04	0.04	0.04
0.04	0.04	0.04	0.04	0.04	0.04
0.10	0.10	0.10	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20	0.10
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.0	1.0	1.0
1.0	1.0	1.0	0.0	0.0	0.0
0.01	0.01	0.01	0.00705	0.00940	0.00705
0.00940	0.00940	0.0047	0.01	0.01	0.01
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.70	0.70	0.70	0.70	0.70	0.70
0.70	0.70	0.70	0.70	0.70	0.70
0.010	1.0	0.0	3.6576		

PREVIOUS PAGE IS BLANK

Table A2. INPUT file.

```
   85   93
ROWS
 E   1   12  11.513
 E  13   24   0 0
 G  25   36   0.0
 E  37   48   0.0
 E  49   60   0.0
 E  61   72   0.4E05
 G  73        0 0
 N  74   85
 O  86
 N  87   93
END
BOUNDS
 G   1    1  0.0
 R   2   13   .5299                55.0
 E  14   16  0.0
 G  17   24  0.0
 E  25       0.0
 G  26   37  0.0
 G  38   49  0.0
 G  50   61  0.0
 G  62   73  0.0
 E  74   85  0.0
END
INITIAL
SEP
     1       50.0
     2   13  30.0
    14   16   0 0
    17   24  18.9
    25        0.0
    26   28   0.0
    29   36  18 9
    37        0.0
    38   49    .024
    50   52   0.0
    53         .005
    54         .0065
    55         .005
    56   57    .0065
    58         .0033
    59   61   0 0
    62   64   0.0
    65   72    .189
    73        0.0
    74   85   0.0
END
FUNCTIONS
VARIABLES
PRINT
IPR      0
END
GO
```

Table A3. OUTPUT file.

```
1
ONUMBER OF VARIABLES IS     85
ONUMBER OF FUNCTIONS IS     93
OSPACE RESERVED FOR HESSIAN HAS DIMENSION     85
OLIMIT ON BINDING CONSTRAINTS IS     92
OACTUAL LENGTH OF Z ARRAY IS  19075
 ROWS
  E     1   12 1.151300E+01
  E    13   24 0.000000E-01
  G    25   36 0.000000E-01
  E    37   48 0.000000E-01
  E    49   60 0.000000E-01
  E    61   72 4.605000E-01
  G    73   73 0.000000E-01
  N    74   85
  O    86
  N    87   93
 END
 BOUNDS
  G     1    1 0.000000E-01
  R     2   13 5.299000E-01 5.500000E+01
  E    14   16 0.000000E-01
  G    17   24 0.000000E-01
  E    25   25 0.000000E-01
  G    26   37 0.000000E-01
  G    38   49 0.000000E-01
  G    50   61 0.000000E-01
  G    62   73 0.000000E-01
  E    74   85 0.000000E-01
 END
 INITIAL
 SEP
      1    1  5.000000E+01
      2   13  3.000000E+01
     14   16  0.000000E-01
     17   24  1.390000E+01
     25   25  0.000000E-01
     26   28  0.000000E-01
     29   36  1.000000E+01
     37   37  0.000000E-01
     38   49  2.400000E-02
     50   52  0.000000E-01
     53   53  5.000000E-03
     54   54  6.500000E-03
     55   55  5.000000E-03
     56   57  6.500000E-03
     58   58  3.000000E-03
     59   61  0.000000E-01
     62   64  0.000000E-01
     65   72  1.090000E-01
     73   73  0.000000E-01
     74   85  0.000000E-01
 END
 FUNCTIONS
```

```
 VARIABLES
 PRINT
 IPR      0
 END
 GO
OEPNEWT =  1.0000E-04  EPINIT =  1.0000E-04  EPSTOP =  1.0000E-04
  EPPIV =  1.0000E-03  PHIEPS = 0.0000E-01
ONSTOP =    3  ITLIM =   10  LIMSER =      10000
OIPR =   0  PN4 =   0  PN5 =   0  PN6 =   0  PER =   0  DUMP =   0
OTANGENT VECTORS WILL BE USED FOR INITIAL ESTIMATES OF BASIC VARIABLES

OTHE FINITE DIFFERENCE PARSH USING FORWARD DIFFERENCES WILL BE USED

OOBJECTIVE FUNCTION WILL BE MINIMIZED.

ODFP WILL BE USED IF # SUPERBASICCS < = 85
PARAMETERS

  11.512999 11.512999 11.512999 11.512999 11.512999 11.512999
  11.512999 11.512999 11.512999 11.512999 11.512999 11.512999
   0.000000  0.000000  0.000000  0.325000  0.079000  0.086000
   0.039000  0.089000  0.031000  0.079000  0.071000  0.000000
   0.000000  0.000000  0.000000  0.030000  0.077000  0.112000
   0.134000  0.133000  0.076000  0.029000  0.006000  0.000000
   0.000000  0.000000  0.000000  0.000000  0.077000  0.112000
   0.134000  0.113000  0.076000  0.029000  0.006000  0.000000
   0.870000  0.870000  0.870000  0.870000  0.870000  0.870000
   0.870000  0.870000  0.870000  0.370000  0.435000  0.870000
   0.040000  0.040000  0.040000  0.040000  0.040000  0.040000
   0.040000  0.040000  0.040000  0.040000  0.040000  0.040000
   0.100000  0.100000  0.100000  0.200000  0.200000  0.200000
   0.200000  0.200000  0.200000  0.200000  0.200000  0.100000
   0.000000  0.000000  0.000000  0.000000  0.000000  0.000000
   0.000000  0.000000  0.000000  0.000000  0.000000  0.000000
   0.000000  0.000000  0.000000  1.000000  1.000000  1.000000
   1.000000  1.000000  1.000000  0.000000  0.000000  0.000000
   0.010000  0.010000  0.010000  0.007050  0.009400  0.007050
   0.009400  0.009400  0.004700  0.010000  0.010000  0.010000
   1.000000  1.000000  1.000000  1.000000  1.000000  1.000000
   1.000000  1.000000  1.000000  1.000000  1.000000  1.000000
   0.015000  0.015000  0.015000  0.015000  0.015000  0.015000
   0.015000  0.015000  0.015000  0.015000  0.015000  0.015000
   0.700000  0.700000  0.700000  0.700000  0.700000  0.700000
   0.700000  0.700000  0.700000  0.700000  0.700000  0.700000
   0.010000  1.000000  0.000000  3.657600
1                              OUTPUT OF INITIAL VALUES
```

OSECTION 1 -- FUNCTIONS

NO	FUNCTION NAME	STATUS	TYPE	INITIAL VALUE	LOWER LIMIT	UPPER LIMIT
1	LAGOON1	***	EQ	0 [illegible]	1.1513000E+01	1.1513000E+01
2	LAGOON2	***	EQ	0 [illegible]	1.1513000E+01	1.1513000E+01
3	LAGOON3	***	EQ	0 [illegible]	1.1513000E+01	1.1513000E+01
4	LAGOON4	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
5	LAGOON5	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
6	LAGOON6	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
7	LAGOON7	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
8	LAGOON8	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
9	LAGOON9	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
10	LAGOON10	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
11	LAGOON11	***	EQ	1 [illegible]	1.1513000E+01	1.1513000E+01
12	LAGOON12	***	EQ	0 [illegible]	1.1513000E+01	1.1513000E+01
13	H2O BL1	EQ	EQ	0 0.0000000E-01	0.0000000E-01	0.0000000E-01
14	H2O BL2	EQ	EQ	0 0.0000000E-01	0.0000000E-01	0.0000000E-01
15	H2O BL3	EQ	EQ	0 0.0000000E-01	0.0000000E-01	0.0000000E-01
16	H2O BL4	***	EQ	9 [illegible]	0.0000000E-01	0.0000000E-01
17	H2O BL5	***	EQ	-5 [illegible]	0.0000000E-01	0.0000000E-01
18	H2O BL6	***	EQ	-6 [illegible]	0.0000000E-01	0.0000000E-01
19	H2O BL7	***	EQ	-7 [illegible]	0.0000000E-01	0.0000000E-01
20	H2O BL8	***	EQ	-6 [illegible]	0.0000000E-01	0.0000000E-01
21	H2O BL9	***	EQ	-5 [illegible]	0.0000000E-01	0.0000000E-01
22	H2O BL10	***	EQ	-3 [illegible]	0.0000000E-01	0.0000000E-01
23	H2O BL11	***	EQ	-2 [illegible]	0.0000000E-01	0.0000000E-01
24	H2O BL12	EQ	EQ	0 [illegible]	0.0000000E-01	0.0000000E-01
25	DRA CP1		GE	4 [illegible]	0.0000000E-01	NONE
26	DRA CP2		GE	4 [illegible]	0.0000000E-01	NONE
27	DRA CP3		GE	4 [illegible]	0.0000000E-01	NONE
28	DRA CP4		GE	2 [illegible]	0.0000000E-01	NONE
29	DRA CP5		GE	2 [illegible]	0.0000000E-01	NONE
30	DRA CP6		GE	2 [illegible]	0.0000000E-01	NONE
31	DRA CP7		GE	2 [illegible]	0.0000000E-01	NONE
32	DRA CP8		GE	2 [illegible]	0.0000000E-01	NONE
33	DRA CP9		GE	2 [illegible]	0.0000000E-01	NONE
34	DRA CP10		GE	2 [illegible]	0.0000000E-01	NONE
35	DRA CP11		GE	2 [illegible]	0.0000000E-01	NONE
36	DRA CP12		GE	4 [illegible]	0.0000000E-01	NONE
37	N BAL1	EQ	EQ	0 [illegible]	0.0000000E-01	0.0000000E-01
38	N BAL2	EQ	EQ	0 [illegible]	0.0000000E-01	0.0000000E-01
39	N BAL3	EQ	EQ	0 [illegible]	0.0000000E-01	0.0000000E-01
40	N BAL4	***	EQ	-1 [illegible]	0.0000000E-01	0.0000000E-01
41	N BAL5	***	EQ	6 [illegible]	0.0000000E-01	0.0000000E-01
42	N BAL6	***	EQ	-1 [illegible]	0.0000000E-01	0.0000000E-01
43	N BAL7	***	EQ	6 [illegible]	0.0000000E-01	0.0000000E-01
44	N BAL8	***	EQ	6 [illegible]	0.0000000E-01	0.0000000E-01
45	N BAL9	***	EQ	-9 [illegible]	0.0000000E-01	0.0000000E-01
46	N BAL10	***	EQ	-2 [illegible]	0.0000000E-01	0.0000000E-01
47	N BAL11	***	EQ	-2 [illegible]	0.0000000E-01	0.0000000E-01
48	N BAL12	EQ	EQ	0 [illegible]	0.0000000E-01	0.0000000E-01
49	N CROP1	EQ	EQ	0 [illegible]	0.0000000E-01	0.0000000E-01
50	N CROP2	EQ	EQ	0 0.0000000E-01	0.0000000E-01	0.0000000E-01
51	N CROP3	EQ	EQ	0 0.0000000E-01	0.0000000E-01	0.0000000E-01
52	N CROP4	***	EQ	-1 [illegible]	0.0000000E-01	0.0000000E-01
53	N CROP5	***	EQ	6 [illegible]	0.0000000E-01	0.0000000E-01
54	N CROP6	***	EQ	-1 0313720E-04	0.0000000E-01	0.0000000E-01

55	N CROP7	***	EQ	6.8086130E-04	0.0000000E-01	0.0000000E-01
56	N CROP8	***	EQ	6.8086130E-04	0.0000000E-01	0.0000000E-01
57	N CROP9	***	EQ	-7.1794829E-04	0.0000000E-01	0.0000000E-01
58	N CROP10	EQ	EQ	0.0000000E-01	0.0000000E-01	0.0000000E-01
59	N CROP11	EQ	EQ	0.0000000E-01	0.0000000E-01	0.0000000E-01
60	N CROP12	EQ	EQ	0.0000000E-01	0.0000000E-01	0.0000000E-01
61	LAG N1	***	EQ	7.1999996E-02	4.6050000E-01	4.6050000E-01
62	LAG N2	***	EQ	7.1999996E-02	4.6050000E-01	4.6050000E-01
63	LAG N3	***	EQ	7.1999996E-02	4.6050000E-01	4.6050000E-01
64	LAG N4	***	EQ	5.9759997E-01	4.6050000E-01	4.6050000E-01
65	LAG N5	***	EQ	5.9759997E-01	4.6050000E-01	4.6050000E-01
66	LAG N6	***	EQ	5.9759997E-01	4.6050000E-01	4.6050000E-01
67	LAG N7	***	EQ	5.9759997E-01	4.6050000E-01	4.6050000E-01
68	LAG N8	***	EQ	5.9759999E-01	4.6050000E-01	4.6050000E-01
69	LAG N9	***	EQ	5.9759999E-01	4.6050000E-01	4.6050000E-01
70	LAG N10	***	EQ	5.9759997E-01	4.6050000E-01	4.6050000E-01
71	LAG N11	***	EQ	5.9759997E-01	4.6050000E-01	4.6050000E-01
72	LAG N12	***	EQ	7.1999996E-02	4.6050000E-01	4.6050000E-01
73	GW QUAL	LL	GE	-1.4210855E-14	0.0000000E-01	NONE
74	GWN1		NA	0.0000000E-01		
75	GWN2		NA	0.0000000E-01		
76	GWN3		NA	0.0000000E-01		
77	GWN4		NA	9.4499976E-02		
78	GWN5		NA	9.4499976E-02		
79	GWN6		NA	9.4499976E-02		
80	GWN7		NA	9.4499976E-02		
81	GWN8		NA	9.4499976E-02		
82	GWN9		NA	9.4499976E-02		
83	GW10		NA	9.4499976E-02		
84	GW11		NA	9.4499976E-02		
85	GW12		NA	0.0000000E-01		
86	OBJ		OBJ	5.0000000E+01		
87	STOREVN		NA	1.4299999E+00		
88	STOREVNP		NA	2.6057510E-01		
89	CRUPN		NA	1.6400000E+00		
90	CRUPNP		NA	3.4044128E-01		
91	TOTREVN		NA	3.0799999E+00		
92	TOTREVNP		NA	6.3936545E-01		
93	APPMAX		NA	3.5162797E-01		

OSECTION 2 -- VARIABLES

NO	VARIABLE NAME	STATUS	INITIAL VALUE	LOWER LIMIT	UPPER LIMIT
1	AREA		5.0000000E+01	0.0000000E-01	NONE
2	STOR1		3.0000000E+01	5.2990000E-01	5.5000000E+01
3	STOR2		3.0000000E+01	5.2990000E-01	5.5000000E+01
4	STOR3		3.0000000E+01	5.2990000E-01	5.5000000E+01
5	STOR4		3.0000000E+01	5.2990000E-01	5.5000000E+01
6	STOR5		3.0000000E+01	5.2990000E-01	5.5000000E+01
7	STOR6		3.0000000E+01	5.2990000E-01	5.5000000E+01

8	STOR7		3.00000000E+01	5.29900000E-01	5.50000000E+01
9	STOR8		3.00000000E+01	5.29900000E-01	5.50000000E+01
10	STOR9		3.00000000E+01	5.29900000E-01	5.50000000E+01
11	STOR10		3.00000000E+01	5.29900000E-01	5.50000000E+01
12	STOR11		3.00000000E+01	5.29900000E-01	5.50000000E+01
13	STOR12		3.00000000E+01	5.29900000E-01	5.50000000E+01
14	APP1	FX	0.00000000E-01	0.00000000E-01	0.00000000E-01
15	APP2	FX	0.00000000E-01	0.00000000E-01	0.00000000E-01
16	APP3	FX	0.00000000E-01	0.00000000E-01	0.00000000E-01
17	APP4		1.89000000E+01	0.00000000E-01	NONE
18	APP5		1.89000000E+01	0.00000000E-01	NONE
19	APP6		1.89000000E+01	0.00000000E-01	NONE
20	APP7		1.89000000E+01	0.00000000E-01	NONE
21	APP8		1.89000000E+01	0.00000000E-01	NONE
22	APP9		1.89000000E+01	0.00000000E-01	NONE
23	APP10		1.89000000E+01	0.00000000E-01	NONE
24	APP11		1.89000000E+01	0.00000000E-01	NONE
25	APP12	FX	0.00000000E-01	0.00000000E-01	0.00000000E-01
26	DRAIN1	LL	0.00000000E-01	0.00000000E-01	NONE
27	DRAIN2	LL	0.00000000E-01	0.00000000E-01	NONE
28	DRAIN3	LL	0.00000000E-01	0.00000000E-01	NONE
29	DRAIN4		1.89000000E+01	0.00000000E-01	NONE
30	DRAIN5		1.89000000E+01	0.00000000E-01	NONE
31	DRAIN6		1.89000000E+01	0.00000000E-01	NONE
32	DRAIN7		1.89000000E+01	0.00000000E-01	NONE
33	DRAIN8		1.89000000E+01	0.00000000E-01	NONE
34	DRAIN9		1.89000000E+01	0.00000000E-01	NONE
35	DRAIN10		1.89000000E+01	0.00000000E-01	NONE
36	DRAIN11		1.89000000E+01	0.00000000E-01	NONE
37	DRAIN12	LL	0.00000000E-01	0.00000000E-01	NONE
38	N STOR1		2.40000000E-02	0.00000000E-01	NONE
39	N STOR2		2.40000000E-02	0.00000000E-01	NONE
40	N STOR3		2.40000000E-02	0.00000000E-01	NONE
41	N STOR4		2.40000000E-02	0.00000000E-01	NONE
42	N STOR5		2.40000000E-02	0.00000000E-01	NONE
43	N STOR6		2.40000000E-02	0.00000000E-01	NONE
44	N STOR7		2.40000000E-02	0.00000000E-01	NONE
45	N STOR8		2.40000000E-02	0.00000000E-01	NONE
46	N STOR9		2.40000000E-02	0.00000000E-01	NONE
47	N STOR10		2.40000000E-02	0.00000000E-01	NONE
48	N STOR11		2.40000000E-02	0.00000000E-01	NONE
49	N STOR12		2.40000000E-02	0.00000000E-01	NONE
50	CROP N1	LL	0.00000000E-01	0.00000000E-01	NONE
51	CROP N2	LL	0.00000000E-01	0.00000000E-01	NONE
52	CROP N3	LL	0.00000000E-01	0.00000000E-01	NONE
53	CROP N4		5.00000000E-03	0.00000000E-01	NONE
54	CROP N5		6.50000000E-03	0.00000000E-01	NONE
55	CROP N6		5.00000000E-03	0.00000000E-01	NONE
56	CROP N7		6.50000000E-03	0.00000000E-01	NONE
57	CROP N8		6.50000000E-03	0.00000000E-01	NONE
58	CROP N9		3.30000000E-03	0.00000000E-01	NONE
59	CROP N10	LL	0.00000000E-01	0.00000000E-01	NONE
60	CROP N11	LL	0.00000000E-01	0.00000000E-01	NONE
61	CROP N12	LL	0.00000000E-01	0.00000000E-01	NONE

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  62  N PERC1     LL      0.00000000E-01   0.00000000E-01        NONE
  63  N PERC2     LL      0.00000000E-01   0.00000000E-01        NONE
  64  N PERC3     LL      0.00000000E-01   0.00000000E-01        NONE
  65  N PERC4             1.89000000E-01   0.00000000E-01        NONE
  66  N PERC5             1.89000000E-01   0.00000000E-01        NONE
  67  N PERC6             1.89000000E-01   0.00000000E-01        NONE
  68  N PERC7             1.89000000E-01   0.00000000E-01        NONE
  69  N PERC8             1.89000000E-01   0.00000000E-01        NONE
  70  N PERC9             1.89000000E-01   0.00000000E-01        NONE
  71  N PERC10            1.89000000E-01   0.00000000E-01        NONE
  72  N PERC11            1.89000000E-01   0.00000000E-01        NONE
  73  N PERC12    LL      0.00000000E-01   0.00000000E-01        NONE
  74  BYPASS1     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  75  BYPASS2     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  76  BYPASS3     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  77  BYPASS4     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  78  BYPASS5     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  79  BYPASS6     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  80  BYPASS7     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  81  BYPASS8     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  82  BYPASS9     FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  83  BYPASS10    FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  84  BYPASS11    FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
  85  BYPASS12    FX      0.00000000E-01   0.00000000E-01   0.00000000E-01
1

OTOTAL FRACTIONAL CHANGE IN OBJECTIVE LESS THAN  1.00000E-04 FOR
1                FINAL RESULTS
                                        FOR   3 CONSECUTIVE ITERATIONS
0
OSECTION 1 -- FUNCTIONS

                                                                  DISTANCE
                                                                    FROM
 NO.    NAME        INITIAL VALUE      FINAL VALUE      STATUS    NEAREST     LAGRANGE MULTIPLIER
                                                                   BOUND

   1  LAGOON1   0.00000E-01  1.15130E+01  EQUALITY  0.00000E-01   0.00000E-01
   2  LAGOON2   0.00000E-01  1.15130E+01  EQUALITY  0.00000E-01   0.00000E-01
   3  LAGOON3   0.00000E-01  1.15130E+01  EQUALITY  0.00000E-01   0.00000E-01
   4  LAGOON4   1.64804E+01  1.15130E+01  EQUALITY-3.41IE-13      0.00000E-01
   5  LAGOON5   1.58836E+01  1.15130E+01  EQUALITY-3.411E-13      0.00000E-01
   6  LAGOON6   1.91133E+01  1.15130E+01  EQUALITY-2.169E-09      0.00000E-01
   7  LAGOON7   1.92691E+01  1.15130E+01  EQUALITY-2.356E-09      0.00000E-01
   8  LAGOON8   1.92609E+01  1.15130E+01  EQUALITY-9.840E-09      0.00000E-01
   9  LAGOON9   1.89590E+01  1.15130E+01  EQUALITY-1.098E-08      0.00000E-01
  10  LAGOON10  1.85719E+01  1.15130E+01  EQUALITY-4.422E-08      0.00000E-01
  11  LAGOON11  1.83669E+01  1.15130E+01  EQUALITY-3.649E-08      0.00000E-01
  12  LAGOON12  0.00000E-01  1.15130E+01  EQUALITY  0.00000E-01   0.00000E-01
  13  H2O BL1   0.00000E-01  0.00000E-01  EQUALITY  0.00000E-01   0.00000E-01
  14  H2O BL2   0.00000E-01  0.00000E-01  EQUALITY  0.00000E-01   0.00000E-01
  15  H2O BL3   0.00000E-01  0.00000E-01  EQUALITY  0.00000E-01   0.00000E-01
  16  H2O BL4   9.08000E+00-6.67023E-08  EQUALITY-6.670E-08      0.00000E-01
  17  H2O BL5  -5.57000E+00-5.25233E-10  EQUALITY-5.252E-10      0.00000E-01
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18	H2O	BL6	-6	47000E+00	-1	18697E-09	EQUALITY	-1	187E-08	0.00000E-01
19	H2O	BL7	-7	92000E+00	2	37007E-08	EQUALITY	-7	370E-08	0.00000E-01
20	H2O	BL8	-6	87000E+00	1	48611E-09	EQUALITY	-1	486E-09	0.00000E-01
21	H2O	BL9	-5	48000E+00	6	85804E-09	EQUALITY	-6	858E-09	0.00000E-01
22	H2O	BL10	-3	67000E+00	-1	43912E-08	EQUALITY	-1	439E-08	0.00000E-01
23	H2O	BL11	-2	42000E+00	-3	80957E-08	EQUALITY	-3	810E-08	0.00000E-01
24	H2O	BL12	0	00000E-01	0	00000E-01	EQUALITY	0	000E-01	0.00000E-01
25	DRA	CP1	4	35000E+01	1	11678E+02	FREE	1	117E+02	L
26	DRA	CP2	4	35000E+01	1	11678E+02	FREE	1	117E+02	L
27	DRA	CP3	4	35000E+01	1	11678E+02	FREE	1	117E+02	L
28	DRA	CP4	2	45000E+01	6	26447E+01	FREE	6	264E+01	L
29	DRA	CP5	2	46000E+01	1	03359E+02	FREE	1	033E+02	L
30	DRA	CP6	2	46000E+01	1	02216E+02	FREE	1	022E+02	L
31	DRA	CP7	2	46000E+01	1	02382E+02	FREE	1	024E+02	L
32	DRA	CP8	2	46000E+01	8	87446E+01	FREE	8	874E+01	L
33	DRA	CP9	2	46000E+01	9	76607E+01	FREE	9	766E+01	L
34	DRA	CP10	2	46000E+01	1	06542E+02	FREE	1	065E+02	L
35	DRA	CP11	2	95000E+00	3	42106E+01	FREE	3	421E+01	L
36	DRA	CP12	4	35000E+01	1	11676E+02	FREE	1	117E+02	L
37	N	BAL1		0.00000E-01	0	00000E-01	EQUALITY	0	000E-01	0.00000E-01
38	N	BAL2		0.00000E-01	0	00000E-01	EQUALITY	0	000E-01	0.00000E-01
39	N	BAL3		0.00000E-01	0	00000E-01	EQUALITY	0	000E-01	0.00000E-01

1 FINAL RESULTS

0

OSECTION 1 -- FUNCTIONS

NO.	NAME	INITIAL VALUE	FINAL VALUE	STATUS	DISTANCE FROM NEAREST BOUND	LAGRANGE MULTIPLIER
40	N	BAL4 -1 46000E-02	-6 33200E-05	EQUALITY	-6 332E-05	0.00000E-01
41	N	BAL5 6 04000E-02	-1 83199E-05	EQUALITY	-1 832E-05	0.00000E-01
42	N	BAL6 -1 46000E-02	-6 40871E-05	EQUALITY	-6 409E-05	0.00000E-01
43	N	BAL7 6 04000E-02	-2 72019E-05	EQUALITY	-2 720E-05	0.00000E-01
44	N	BAL8 6 04000E-02	-3 40280E-05	EQUALITY	-3 403E-05	0.00000E-01
45	N	BAL9 -9 96000E-02	1 67517E-05	EQUALITY	-1 675E-05	0.00000E-01
46	N	BAL10 -2 64600E-01	1 45831E-13	EQUALITY	-1 458E-13	0.00000E-01
47	N	BAL11 -2 64600E-01	-3 52306E-06	EQUALITY	-3 523E-06	0.00000E-01
48	N	BAL12 0 00000E-01	0 00000E-01	EQUALITY	0 000E-01	0.00000E-01
49	N	CROP1 0 00000E-01	0 00000E-01	EQUALITY	0 000E-01	0.00000E-01
50	N	CROP2 0 00000E-01	0 00000E-01	EQUALITY	0 000E-01	0.00000E-01
51	N	CROP3 0 00000E-01	0 00000E-01	EQUALITY	0 000E-01	0.00000E-01
52	N	CROP4 -1 03137E-04	5 01093E-05	EQUALITY	-5 011E-05	0.00000E-01
53	N	CROP5 6 80861E-04	-1 27695E-07	EQUALITY	-1 277E-07	0.00000E-01
54	N	CROP6 -1 03137E-04	6 18013E-05	EQUALITY	-6 180E-05	0.00000E-01
55	N	CROP7 6 80861E-04	-1 64624E-07	EQUALITY	-1 646E-07	0.00000E-01
56	N	CROP8 6 80861E-04	-1 69634E-07	EQUALITY	-1 696E-07	0.00000E-01
57	N	CROP9 -7 17948E-04	5 18972E-08	EQUALITY	-5 189E-08	0.00000E-01
58	N	CROP10 0 00000E-01	1 13566E-15	EQUALITY	-1 136E-15	0.00000E-01
59	N	CROP11 0 00000E-01	5 00110E-15	EQUALITY	-5 001E-15	0.00000E-01
60	N	CROP12 0 00000E-01	0 00000E-01	EQUALITY	0 000E-01	0.00000E-01
61	LAG	N1 7 20000E-02	4 60500E-01	EQUALITY	-9 343E-11	0.00000E-01

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  62 LAG N2    7.20000E-02 4.60500E-01 EQUALITY-4.627E-11    0.00000E-01
  63 LAG N3    7.20000E-02 4.60500E-01 EQUALITY-6.774E-11    0.00000E-01
  64 LAG N4    5.97600E-01 4.60500E-01 EQUALITY-7.450E-11    0.00000E-01
  65 LAG N5    5.97600E-01 4.60500E-01 EQUALITY-4.206E-11    0.00000E-01
  66 LAG N6    5.97600E-01 4.60500E-01 EQUALITY-2.108E-08    0.00000E-01
  67 LAG N7    5.97600E-01 4.60500E-01 EQUALITY-5.077E-08    0.00000E-01
  68 LAG N8    5.97600E-01 4.60497E-01 EQUALITY-3.291E-06    0.00000E-01
  69 LAG N9    5.97600E-01 4.60400E-01 EQUALITY-9.990E-05    0.00000E-01
  70 LAG N10   5.97600E-01 4.60558E-01 EQUALITY-5.845E-05    0.00000E-01
  71 LAG N11   5.97600E-01 4.60500E-01 EQUALITY-1.593E-07    0.00000E-01
  72 LAG N12   7.20000E-02 4.60500E-01 EQUALITY-1.125E-10    0.00000E-01
  73 GW QUAL  -1.42109E-14-2.28367E-09 LOWERBND-2.284E-09 L  0.00000E-01
  74 GWN1      0.00000E-01 0.00000E-01 IGNORED  1.000E+30
  75 GWN2      0.00000E-01 0.00000E-01 IGNORED  1.000E+30
  76 GWN3      0.00000E-01 0.00000E-01 IGNORED  1.000E+30
  77 GWN4      9.45000E-02 6.46115E-01 IGNORED  1.000E+30
  78 GWN5      9.45000E-02 9.39457E-02 IGNORED  1.000E+30
  79 GWN6      9.45000E-02 6.28036E-02 IGNORED  1.000E+30
1                FINAL RESULTS

0
0SECTION 1 -- FUNCTIONS

                                                  DISTANCE
                 INITIAL       FINAL                 FROM       LAGRANGE
 NO.    NAME      VALUE        VALUE      STATUS    NEAREST     MULTIPLIER
                                                    BOUND

  80 GWN7      9.45000E-02 4.94007E-02 IGNORED  1.000E+30
  81 GWN8      9.45000E-02 7.51945E-02 IGNORED  1.000E+30
  82 GWN9      9.45000E-02-2.28090E-03 IGNORED  1.000E+30
  83 GW10      9.45000E-02 7.70181E-02 IGNORED  1.000E+30
  84 GW11      9.45000E-02-3.03036E-01 IGNORED  1.000E+30
  85 GW12      0.00000E-01 0.00000E-01 IGNORED  1.000E+30
  86 OBJ       5.00000E+01 1.28363E+02   OBJ
  87 STOREVN   1.44000E+00 1.73939E+00 IGNORED  1.000E+30
  88 STOREVNP  2.60575E-01 3.14752E-01 IGNORED  1.000E+30
  89 CRUPN     1.64000E+00 2.38537E+00 IGNORED  1.000E+30
  90 CRUPNP    3.40441E-01 4.95170E-01 IGNORED  1.000E+30
  91 TOTREVN   3.08000E+00 4.12476E+00 IGNORED  1.000E+30
  92 TOTREVNP  6.39365E-01 8.56244E-01 IGNORED  1.000E+30
  93 APPMAX    3.51628E-01 1.36318E-01 IGNORED  1.000E+30
1                FINAL RESULTS

0

0SECTION 2 -- VARIABLES

                                                  DISTANCE
                 INITIAL       FINAL                 FROM       REDUCED
 NO.    NAME      VALUE        VALUE      STATUS    NEAREST     GRADIENT
                                                    BOUND

   1 AREA      5.00000E+01 1.28363E+02 SUPBASIC 1.284E+02 L  1.00000E+00
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   2 STOR1      3 00000E+01  3 19740E+01   BASIC     2 30?E+01 U
   3 STOR2      3 00000E+01  4 34870E+01   BASIC     1 151E+01 U
   4 STOR3      3 00000E+01  5 50000E+01 NONBASIC   UPPERBND     0.00000E-01
   5 STOR4      3 00000E+01  5 50000E+01 NONBASIC   UPPERBND     0.00000E-01
   6 STOR5      3 00000E+01  5 50000E+01 NONBASIC   UPPERBND     0.00000E-01
   7 STOR6      3 00000E+01  4 78393E+01   BASIC     7 161E+00 U
   8 STOR7      3 00000E+01  3 71463E+01   BASIC     1 785E+01 U
   9 STOR8      3 00000E+01  1 08371E+01   BASIC     1 031E+01 L
  10 STOR9      3 00000E+01  3 32001E+00   BASIC     2 790E+00 L
  11 STOR10     3 00000E+01  1 54315E+01   BASIC     1 490E+01 L
  12 STOR11     3 00000E+01  8 94200E+00   BASIC     8 418E+00 L
  13 STOR12     3 00000E+01  2 04610E+01   BASIC     1 993E+01 L
  14 APP1       0 00000E-01  0 00000E-01 NONBASIC     FIXED      0.00000E-01
  15 APP2       0 00000E-01  0 00000E-01 NONBASIC     FIXED      0.00000E-01
  16 APP3       0 00000E-01  0 00000E-01 NONBASIC     FIXED      0.00000E-01
  17 APP4       1 89000E+01  1 59490E+01   BASIC     1 595E+01 L
  18 APP5       1 89000E+01  1 15431E+01   BASIC     1 154E+01 L
  19 APP6       1 89000E+01  1 82327E+01   BASIC     1 828E+01 L
  20 APP7       1 89000E+01  2 13294E+01 SUPBASIC   2 132E+01 L 0.00000E-01
  21 APP8       1 89000E+01  3 71603E+01 SUPBASIC   3 716E+01 L 0.00000E-01
  22 APP9       1 89000E+01  1 91053E+01 SUPBASIC   1 911E+01 L 0.00000E-01
  23 APP10      1 89000E+01-4 64476E-14 NONBASIC   LOWERBND     0.00000E-01
  24 APP11      1 89000E+01  1 89?6?E+01 SUPBASIC   1 898E+01 L 0.00000E-01
  25 APP12      0 00000E-01  0 00000E-01 NONBASIC     FIXED      0.00000E-01
  26 DRAIN1     0 00000E-01  0 00000E-01   BASIC     LOWERBND
  27 DRAIN2     0 00000E-01  0 00000E-01   BASIC     LOWERBND
  28 DRAIN3     0 00000E-01  0 00000E-01   BASIC     LOWERBND
  29 DRAIN4     1 89000E+01  4 90315E+01   BASIC     4 903E+01 L
  30 DRAIN5     1 89000E+01  8 33688E+00   BASIC     8 337E+00 L
  31 DRAIN6     1 89000E+01  9 46047E+00   BASIC     9 460E+00 L
  32 DRAIN7     1 89000E+01  9 29420E+00   BASIC     9 294E+00 L
  33 DRAIN8     1 89000E+01  2 29316E+01   BASIC     2 293E+01 L
  34 DRAIN9     1 89000E+01  1 40155E+01   BASIC     1 402E+01 L
  35 DRAIN10    1 89000E+01  5 13454E+00   BASIC     5 135E+00 L
  36 DRAIN11    1 89000E+01  2 16275E+01   BASIC     2 163E+01 L
  37 DRAIN12    0 00000E-01  0 00000E-01   BASIC     LOWERBND
  38 N STOR1    2 40000E-02  3 32774E-02   BASIC     3 328E-02 L
  39 N STOR2    2 40000E-02  3 22220E-02   BASIC     3 222E-02 L
1                FINAL RESULTS

0

OSECTION 2 -- VARIABLES

                                                                DISTANCE
                                                                  FROM
 NO     NAME      INITIAL VALUE      FINAL VALUE      STATUS    NEAREST      REDUCED GRADIENT
                                                                BOUND

  40 N STOR3    2 40000E-02  3 10249E-02   BASIC     3 102E-02 L
  41 N STOR4    2 40000E-02  2 55398E-02   BASIC     2 554E-02 L
  42 N STOR5    2 40000E-02  2 38008E-02   BASIC     2 380E-02 L
  43 N STOR6    2 40000E-02  2 29995E-02   BASIC     2 300E-02 L
  44 N STOR7    2 40000E-02  2 33140E-02   BASIC     2 331E-02 L
```

```
  45 N STOR8   2.40000E-02 2.80221E-02  BASIC    2.802E-02 L
  46 N STOR9   2.40000E-02 3.98271E-02  BASIC    3.983E-02 L
  47 N STOR10  2.40000E-02 3.41362E-02  BASIC    3.414E-02 L
  48 N STOR11  2.40000E-02 3.12143E-02  BASIC    3.121E-02 L
  49 N STOR12  2.40000E-02 3.37851E-02  BASIC    3.379E-02 L
  50 CROP N1   0.00000E-01 0.00000E-01  BASIC     LOWERBND
  51 CROP N2   0.00000E-01 0.00000E-01  BASIC     LOWERBND
  52 CROP N3   0.00000E-01 0.00000E-01  BASIC     LOWERBND
  53 CROP N4   5.00000E-03 2.81741E-03  BASIC    2.817E-03 L
  54 CROP N5   6.50000E-03 1.97599E-03  BASIC    1.976E-03 L
  55 CROP N6   5.00000E-03 2.72010E-03  BASIC    2.720E-03 L
  56 CROP N7   6.50000E-03 3.17914E-03  BASIC    3.179E-03 L
  57 CROP N8   6.50000E-03 4.96294E-03  BASIC    4.963E-03 L
  58 CROP N9   3.30000E-03 2.92736E-03  BASIC    2.927E-03 L
  59 CROP N10  0.00000E-01 1.13566E-15  BASIC     LOWERBND
  60 CROP N11  0.00000E-01 5.00110E-15  BASIC     LOWERBND
  61 CROP N12  0.00000E-01 0.00000E-01  BASIC     LOWERBND
  62 N PERC1   0.00000E-01 0.00000E-01 NONBASIC  LOWERBND   0.00000E-01
  63 N PERC2   0.00000E-01 0.00000E-01 NONBASIC  LOWERBND   0.00000E-01
  64 N PERC3   0.00000E-01 0.00000E-01 NONBASIC  LOWERBND   0.00000E-01
  65 N PERC4   1.89000E-01 8.93578E-02  BASIC    8.936E-02 L
  66 N PERC5   1.89000E-01 3.11075E-02  BASIC    3.111E-02 L
  67 N PERC6   1.89000E-01 7.91033E-02  BASIC    7.910E-02 L
  68 N PERC7   1.89000E-01 9.00123E-02  BASIC    9.001E-02 L
  69 N PERC8   1.89000E-01 2.68780E-01  BASIC    2.688E-01 L
  70 N PERC9   1.89000E-01 2.12514E-01  BASIC    2.125E-01 L
  71 N PERC10  1.89000E-01-1.57828E-15 NONBASIC  LOWERBND   0.00000E-01
  72 N PERC11  1.89000E-01 6.27448E-01  BASIC    6.274E-01 L
  73 N PERC12  0.00000E-01 0.00000E-01 NONBASIC  LOWERBND   0.00000E-01
  74 BYPASS1   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  75 BYPASS2   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  76 BYPASS3   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  77 BYPASS4   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  78 BYPASS5   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  79 BYPASS6   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
1                FINAL RESULTS

0

0SECTION 2 -- VARIABLES

                                                   DISTANCE
                 INITIAL       FINAL                  FROM       REDUCED
 NO.    NAME      VALUE        VALUE       STATUS    NEAREST     GRADIENT
                                                      BOUND

  80 BYPASS7   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  81 BYPASS8   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  82 BYPASS9   0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  83 BYPASS10  0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  84 BYPASS11  0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
  85 BYPASS12  0.00000E-01 0.00000E-01 NONBASIC   FIXED     0.00000E-01
1RUN STATISTICS
0


0NUMBER OF ONE-DIMENSIONAL SEARCHES =      71
0NEWTON CALLS =  304  NEWTON ITERATIONS =  267  AVERAGE =     0.88
0FUNCTION CALLS =  569  GRADIENT CALLS =     72
  ACTUAL FUNCTION CALLS (INC. FOR GRADIENT) =    6689
0NUMBER OF TIMES BASIC VARIABLE VIOLATED A BOUND =     44
0NUMBER OF TIMES NEWTON FAILED TO CONVERGE =     17
0TIMES STEPSIZE CUT BACK DUE TO NEWTON FAILURE =     14
```

APPENDIX B: LTMOD program listing.

```
C LTMOD PROGRAM
C
C MAXMEM SETS THE AMOUNT OF MEMORY USED
      PARAMETER MAXMEM = 20000
$INSERT SYSCOM:A$KEYS
      REAL*8 Z(MAXMEM)
      COMMON /FUDGE/Z
      INTEGER *4 NCORE
      INTEGER*2 INFILE(5),OUTFIL(6),INAME(16),OUTNAM(16)
      INTEGER*2 COMSG(9),CONAME(16)
      INTEGER*2 DEFILE(6),DEFNAME(16)
      LOGICAL LOG
      DATA NCORE/MAXMEM/
      DATA INFILE/10HINPUT FILE/
      DATA OUTFIL/11HOUTPUT FILE/
      DATA COMSG/10HPARAM FILE/
      DATA DEFILE/11HDEFINE FILE /
      WRITE(1,100)
100   FORMAT('LAND TREATMENT OPTIMIZATION MODEL')
10    LOG=OPVP$A(INFILE,INTS(10),A$READ,INAME,INTS(32),INTS(1),
     * A$VOLD,0,0)
      IF(.NOT.LOG) GO TO 10
15    LOG=OPVP$A(COMSG,INTS(10),A$READ,CONAME,INTS(32),INTS(3),
     * A$VOLD,0,0)
      IF(.NOT.LOG) GO TO 15
16    LOG=OPVP$A(DEFILE,INTS(10),A$READ,DEFNAME,INTS(32),INTS(4),
     * A$VOLD,0,0)
      IF(.NOT.LOG) GO TO 16
20    LOG=OPVP$A(OUTFIL,INTS(11),A$WRIT,OUTNAM,INTS(32),INTS(2),
     * A$OVAP,0,0)
      IF(.NOT.LOG) GO TO 20
      CALL GRG(Z,NCORE)
      LOG = CLOS$A(INTS(1))
      LOG = CLOS$A(INTS(2))
      LOG = CLOS$A(INTS(3))
      LOG = CLOS$A(INTS(4))
      CALL EXIT
      END
C
      SUBROUTINE GCOMP (G,X)
      IMPLICIT REAL*8(A-Z)
      COMMON/INITBK/INIT
      REAL I(12),P(12),E(12),W(12),MDR(12),NI(12),
     * NK(12),DEN(12),CP(12),MNU(12),FNL(12),NCOM(12),EFF(12)
      SAVE I,P,E,W,MDR,NI,NK,DEN,CP,MNU,FNL,NCOM,EFF,NCO,
     * OA,OB,DP
      IF(INIT.EQ.0) GO TO 30
      READ(7,10)I,P,E,W,MDR,NI,NK,DEN,CP,MNU,FNL,NCOM,EFF,NCO,
     * OA,OB,DP
10    FORMAT(26(6F10.6/),4F10.6)
      WRITE(6,12)
12    FORMAT('PARAMETERS')
      WRITE(6,11)I,P,E,W,MDR,NI,NK,DEN,CP,MNU,FNL,NCOM,EFF,NCO,
     * OA,OB,DP
```

```
C LIMOD PROGRAM


11    FORMAT(25(1X,6F10.6/),1X,4F10.6)
30    CONTINUE
      DIMENSION G(93),X(85)
C
C STORAGE WATER BALANCE
C
      G(1)=X(14)+X(74)+X(2)-X(13)+(E(1)-P(1))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(2)=X(15)+X(75)+X(3)-X(2)+(E(2)-P(2))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(3)=X(16)+X(76)+X(4)-X(3)+(E(3)-P(3))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(4)=X(17)+X(77)+X(5)-X(4)+(E(4)-P(4))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(5)=X(18)+X(78)+X(6)-X(5)+(E(5)-P(5))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(6)=X(19)+X(79)+X(7)-X(6)+(E(6)-P(6))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(7)=X(20)+X(80)+X(8)-X(7)+(E(7)-P(7))*DMAX1(X(2),X(3),
     *X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(8)=X(21)+X(81)+X(9)-X(8)+(E(8)-P(8))*DMAX1(X(2),X(3)
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(9)=X(22)+X(82)+X(10)-X(9)+(E(9)-P(9))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(10)=X(23)+X(83)+X(11)-X(10)+(E(10)-P(10))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(11)=X(24)+X(84)+X(12)-X(11)+(E(11)-P(11))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
      G(12)=X(25)+X(85)+X(13)-X(12)+(E(12)-P(12))*DMAX1(X(2),X(3),
     * X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),X(12),X(13))/DP
C
C WATER BALANCE AT IRRIGATION SITE
C
      G(13)=EFF(1)*(X(14)+X(74))+(P(1)-W(1))*X(1)-X(26)
      G(14)=EFF(2)*(X(15)+X(75))+(P(2)-W(2))*X(1)-X(27)
      G(15)=EFF(3)*(X(16)+X(76))+(P(3)-W(3))*X(1)-X(28)
      G(16)=EFF(4)*(X(17)+X(77))+(P(4)-W(4))*X(1)-X(29)
      G(17)=EFF(5)*(X(18)+X(78))+(P(5)-W(5))*X(1)-X(30)
      G(18)=EFF(6)*(X(19)+X(79))+(P(6)-W(6))*X(1)-X(31)
      G(19)=EFF(7)*(X(20)+X(80))+(P(7)-W(7))*X(1)-X(32)
      G(20)=EFF(8)*(X(21)+X(81))+(P(8)-W(8))*X(1)-X(33)
      G(21)=EFF(9)*(X(22)+X(82))+(P(9)-W(9))*X(1)-X(34)
      G(22)=EFF(10)*(X(23)+X(83))+(P(10)-W(10))*X(1)-X(35)
      G(23)=EFF(11)*(X(24)+X(84))+(P(11)-W(11))*X(1)-X(36)
      G(24)=EFF(12)*(X(25)+X(85))+(P(12)-W(12))*X(1)-X(37)
C
C SOIL DRAINAGE CAPACITY
C
      G(25)=MDR(1)*X(1)-X(26)
      G(26)=MDR(2)*X(1)-X(27)
      G(27)=MDR(3)*X(1)-X(28)
      G(28)=MDR(4)*X(1)-X(29)
      G(29)=MDR(5)*X(1)-X(30)
      G(30)=MDR(6)*X(1)-X(31)
```

```
C LTMOD PROGRAM


      G(31)=MDR(7)*X(1)-X(32)
      G(32)=MDR(8)*X(1)-X(33)
      G(33)=MDR(9)*X(1)-X(34)
      G(34)=MDR(10)*X(1)-X(35)
      G(35)=MDR(11)*X(1)-X(36)
      G(36)=MDR(12)*X(1)-X(37)
C
C NITROGEN BALANCE AT IRRIGATION SITE
C
      G(37)=1.0/FNL(1)*X(62)-(1.0-DEN(1))
     * *(X(14)*(X(38)*X(2)+X(49)*X(13))/(X(2)+X(13))*NI(1)*X(74)
     * +(1.0-FNL(12))/FNL(12)*X(73))+X(1)*X(50)
      G(38)=1.0/FNL(2)*X(63)-(1.0-DEN(2))
     * *(X(15)*(X(39)*X(3)+X(38)*X(2))/(X(3)+X(2))+NI(2)*X(75)
     * +(1.0-FNL(1))/FNL(1)*X(52))+X(1)*X(51)
      G(39)=1.0/FNL(3)*X(64)-(1.0-DEN(3))
     * *(X(16)*(X(40)*X(4)+X(39)*X(3))/(X(4)+X(3))+NI(3)*X(76)
     * +(1.0-FNL(2))/FNL(2)*X(53))+X(1)*X(52)
      G(40)=1.0/FNL(4)*X(65)-(1.0-DEN(4))
     * *(X(17)*(X(41)*X(5)+X(40)*X(4))/(X(5)+X(4))+NI(4)*X(77)
     * +(1.0-FNL(3))/FNL(3)*X(54))+X(1)*X(53)
      G(41)=1.0/FNL(5)*X(66)-(1.0-DEN(5))
     * *(X(18)*(X(42)*X(6)+X(41)*X(5))/(X(6)+X(5))+NI(5)*X(78)
     * +(1.0-FNL(4))/FNL(4)*X(55))+X(1)*X(54)
      G(42)=1.0/FNL(6)*X(67)-(1.0-DEN(6))
     * *(X(19)*(X(43)*X(7)+X(42)*X(6))/(X(7)+X(6))+NI(6)*X(79)
     * +(1.0-FNL(5))/FNL(5)*X(56))+X(1)*X(55)
      G(43)=1.0/FNL(7)*X(68)-(1.0-DEN(7))
     * *(X(20)*(X(44)*X(8)+X(43)*X(7))/(X(8)+X(7))+NI(7)*X(80)
     * +(1.0-FNL(6))/FNL(6)*X(57))+X(1)*X(56)
      G(44)=1.0/FNL(8)*X(69)-(1.0-DEN(8))
     * *(X(21)*(X(45)*X(9)+X(44)*X(8))/(X(9)+X(8))+NI(8)*X(81)
     * +(1.0-FNL(7))/FNL(7)*X(58))+X(1)*X(57)
      G(45)=1.0/FNL(9)*X(70)-(1.0-DEN(9))
     * *(X(22)*(X(46)*X(10)+X(45)*X(9))/(X(10)+X(9))+NI(9)*X(82)
     * +(1.0-FNL(8))/FNL(8)*X(59))+X(1)*X(58)
      G(46)=1.0/FNL(10)*X(71)-(1.0-DEN(10))
     * *(X(23)*(X(47)*X(11)+X(46)*X(10))/(X(11)+X(10))+NI(10)*X(83)
     * +(1.0-FNL(9))/FNL(9)*X(60))+X(1)*X(59)
      G(47)=1.0/FNL(11)*X(72)-(1.0-DEN(11))
     * *(X(24)*(X(48)*X(12)+X(47)*X(11))/(X(12)+X(11))+NI(11)*X(84)
     * +(1.0-FNL(10))/FNL(10)*X(61))+X(1)*X(60)
      G(48)=1.0/FNL(12)*X(73)-(1.0-DEN(12))
     * *(X(25)*(X(49)*X(13)+X(48)*X(12))/(X(13)+X(12))+NI(12)*X(85)
     * +(1.0-FNL(11))/FNL(11)*X(73))+X(1)*X(61))
C
C CROP UPTAKE OF NITROGEN
C
      G(49)=X(50)-CP(1)*MNU(1)
     * *(1.0-EXP(-(NI(1)*X(74)-(1.0-FNL(12))/FNL(12)*X(73))
     * *(X(2)+X(13))/X(14)
     * *(X(38)*X(2)+X(49)*X(13))/(X(2)+X(13))
     * *(X(1)*MNU(1)))))
      G(50)=X(51)-CP(2)*MNU(2)
```

```
C LIMOD PROGRAM

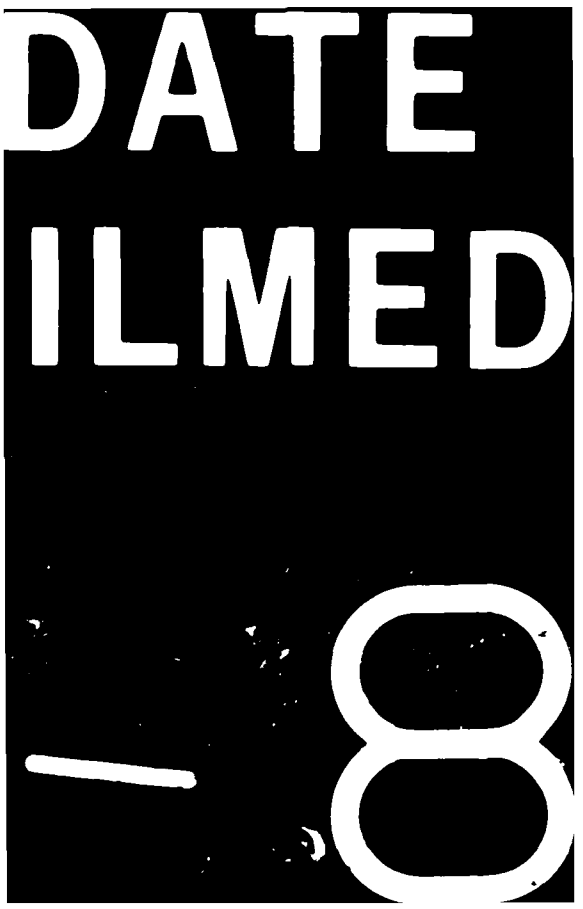
     * *(1.0-EXP(((-NI(2)*X(75)-(1.0-FNL(1))/FNL(1)*X(62))
     * *(X(3)+X(2))-X(15)
     * *(X(39)*X(3)+X(38)*X(2)))/((X(3)+X(2))
     * *(X(1)*MNU(2)))))
      G(51)=X(52)-CP(3)*MNU(3)
     * *(1.0-EXP(((-NI(3)*X(76)-(1.0-FNL(2))/FNL(2)*X(63))
     * *(X(4)+X(3))-X(16)
     * *(X(40)*X(4)+X(39)*X(3)))/((X(4)+X(3))
     * *(X(1)*MNU(3)))))
      G(52)=X(53)-CP(4)*MNU(4)
     * *(1.0-EXP(((-NI(4)*X(77)-(1.0-FNL(3))/FNL(3)*X(64))
     * *(X(5)+X(4))-X(17)
     * *(X(41)*X(5)+X(40)*X(4)))/((X(5)+X(4))
     * *(X(1)*MNU(4)))))
      G(53)=X(54)-CP(5)*MNU(5)
     * *(1.0-EXP(((-NI(5)*X(78)-(1.0-FNL(4))/FNL(4)*X(65))
     * *(X(6)+X(5))-X(18)
     * *(X(42)*X(6)+X(41)*X(5)))/((X(6)+X(5))
     * *(X(1)*MNU(5)))))
      G(54)=X(55)-CP(6)*MNU(6)
     * *(1.0-EXP(((-NI(6)*X(79)-(1.0-FNL(5))/FNL(5)*X(66))
     * *(X(7)+X(6))-X(19)
     * *(X(43)*X(7)+X(42)*X(6)))/((X(7)+X(6))
     * *(X(1)*MNU(6)))))
      G(55)=X(56)-CP(7)*MNU(7)
     * *(1.0-EXP(((-NI(7)*X(80)-(1.0-FNL(6))/FNL(6)*X(67))
     * *(X(8)+X(7))-X(20)
     * *(X(44)*X(8)+X(43)*X(7)))/((X(8)+X(7))
     * *(X(1)*MNU(7)))))
      G(56)=X(57)-CP(8)*MNU(8)
     * *(1.0-EXP(((-NI(8)*X(81)-(1.0-FNL(7))/FNL(7)*X(68))
     * *(X(9)+X(8))-X(21)
     * *(X(45)*X(9)+X(44)*X(8)))/((X(9)+X(8))
     * *(X(1)*MNU(8)))))
      G(57)=X(58)-CP(9)*MNU(9)
     * *(1.0-EXP(((-NI(9)*X(82)-(1.0-FNL(8))/FNL(8)*X(69))
     * *(X(10)+X(9))-X(22)
     * *(X(46)*X(10)+X(45)*X(9)))/((X(10)+X(9))
     * *(X(1)*MNU(9)))))
      G(58)=X(59)-CP(10)*MNU(10)
     * *(1.0-EXP(((-NI(10)*X(83)-(1.0-FNL(9))/FNL(9)*X(70))
     * *(X(11)+X(10))-X(23)
     * *(X(47)*X(11)+X(46)*X(10)))/((X(11)+X(10))
     * *(X(1)*MNU(10)))))
      G(59)=X(60)-CP(11)*MNU(11)
     * *(1.0-EXP(((-NI(11)*X(84)-(1.0-FNL(10))/FNL(10)*X(71))
     * *(X(12)+X(11))-X(24)
     * *(X(48)*X(12)+X(47)*X(11)))/((X(12)+X(11))
     * *(X(1)*MNU(11)))))
      G(60)=X(61)-CP(12)*MNU(12)
     * *(1.0-EXP(((-NI(12)*X(85)-(1.0-FNL(11))/FNL(11)*X(72))
     * *(X(13)+X(12))-X(25)
     * *(X(49)*X(13)+X(48)*X(12)))/((X(13)+X(12))
     * *(X(1)*MNU(12)))))
```

```
C LIMOD PROGRAM


C
C NITROGEN BALANCE IN STORAGE
C
      G(61)=X(38)*X(2)-X(49)*X(13)+X(14)*(X(38)*X(2)+X(49)*X(13))
     * /(X(2)+X(13))+.5*NK(1)*(X(38)*X(2)+X(49)*X(13))+NI(1)*X(74)
      G(62)=X(39)*X(3)-X(38)*X(2)+X(15)*(X(39)*X(3)+X(38)*X(2))
     * /(X(3)+X(2))+.5*NK(2)*(X(38)*X(2)+X(39)*X(3))+NI(2)*X(75)
      G(63)=X(40)*X(4)-X(39)*X(3)+X(16)*(X(40)*X(4)+X(39)*X(3))
     * /(X(3)+X(4))+.5*NK(3)*(X(40)*X(4)+X(39)*X(3))+NI(3)*X(76)
      G(64)=X(41)*X(5)-X(40)*X(4)+X(17)*(X(41)*X(5)+X(40)*X(4))
     * /(X(5)+X(4))+.5*NK(4)*(X(40)*X(4)+X(41)*X(5))+NI(4)*X(77)
      G(65)=X(42)*X(6)-X(41)*X(5)+X(18)*(X(42)*X(6)+X(41)*X(5))
     * /(X(6)+X(5))+.5*NK(5)*(X(41)*X(5)+X(42)*X(6))+NI(5)*X(78)
      G(66)=X(43)*X(7)-X(42)*X(6)+X(19)*(X(43)*X(7)+X(42)*X(6))
     * /(X(7)+X(6))+.5*NK(6)*(X(43)*X(7)+X(42)*X(6))+NI(6)*X(79)
      G(67)=X(44)*X(8)-X(43)*X(7)+X(20)*(X(44)*X(8)+X(43)*X(7))
     * /(X(8)+X(7))+.5*NK(7)*(X(44)*X(8)+X(43)*X(7))+NI(7)*X(80)
      G(68)=X(45)*X(9)-X(44)*X(8)+X(21)*(X(45)*X(9)+X(44)*X(8))
     * /(X(9)+X(8))+.5*NK(8)*(X(45)*X(9)+X(44)*X(8))+NI(8)*X(81)
      G(69)=X(46)*X(10)-X(45)*X(9)+X(22)*(X(46)*X(10)+X(45)*X(9))
     * /(X(10)+X(9))+.5*NK(9)*(X(45)*X(9)+X(46)*X(10))+NI(9)*X(82)
      G(70)=X(47)*X(11)-X(46)*X(10)+X(23)*(X(47)*X(11)+X(46)*X(10))
     * /(X(11)+X(10))+.5*NK(10)*(X(47)*X(11)+X(46)*X(10))+NI(10)*X(83)
      G(71)=X(48)*X(12)-X(47)*X(11)+X(24)*(X(48)*X(12)+X(47)*X(11))
     * /(X(12)+X(11))+.5*NK(11)*(X(48)*X(12)+X(47)*X(11))+NI(11)*X(84)
      G(72)=X(49)*X(13)-X(48)*X(12)+X(25)*(X(49)*X(13)+X(48)*X(12))
     * /(X(12)+X(13))+.5*NK(12)*(X(48)*X(12)+X(49)*X(13))+NI(12)*X(85)
C
C NITROGEN CONC. IN PERCOLATE CONSTRAINT
C
      G(73)=NCQ*(X(26)+X(27)+X(28)+X(29)
     * +X(30)+X(31)+X(32)+X(33)+X(34)
     * +X(35)+X(36)+X(37))-(X(62)+X(63)+X(64)
     * +X(65)+X(66)+X(67)+X(68)+X(69)
     * +X(70)+X(71)+X(72)+X(73))
C
C MONTHLY QUALITY OF PERCOLATE CONSTRAINTS
C
      G(74)=NCQM(1)*X(26)-X(62)
      G(75)=NCQM(2)*X(27)-X(63)
      G(76)=NCQM(3)*X(28)-X(64)
      G(77)=NCQM(4)*X(29)-X(65)
      G(78)=NCQM(5)*X(30)-X(66)
      G(79)=NCQM(6)*X(31)-X(67)
      G(80)=NCQM(7)*X(32)-X(68)
      G(81)=NCQM(8)*X(33)-X(69)
      G(82)=NCQM(9)*X(34)-X(70)
      G(83)=NCQM(10)*X(35)-X(71)
      G(84)=NCQM(11)*X(36)-X(72)
      G(85)=NCQM(12)*X(37)-X(73)
C
C OBJECTIVE FUNCTION
C
      G(86)=OA*X(1)+OB*DMAX1(X(2),X(3),X(4),X(5),X(6),
```

```
C LTMOD PROGRAM


     * X(7),X(8),X(9),X(10),X(11),X(12))
C
C NITROGEN REMOVED IN STORAGE
C
      G(87)= .5*NK(1)*(X(38)*X(2)+X(47)*X(13))
     * +.5*NK(2)*(X(39)*X(3)+X(38)*X(2))
     * +.5*NK(3)*(X(40)*X(4)+X(39)*X(3))
     * +.5*NK(4)*(X(41)*X(5)+X(40)*X(4))
     * +.5*NK(5)*(X(42)*X(6)+X(41)*X(5))
     * +.5*NK(6)*(X(43)*X(7)+X(44)*X(6))
     * +.5*NK(7)*(X(44)*X(8)+X(43)*X(7))
     * +.5*NK(8)*(X(45)*X(9)+X(44)*X(8))
     * +.5*NK(9)*(X(46)*X(10)+X(45)*X(9))
     * +.5*NK(10)*(X(47)*X(11)+X(46)*X(10))
     * +.5*NK(11)*(X(48)*X(12)+X(47)*X(11))
     * +.5*NK(12)*(X(49)*X(13)+X(48)*X(12))
C
C PERCENTAGE OF NITROGEN REMOVED IN STORAGE
C
      G(88)=G(87)/(NI(1)*I(1)+NI(2)*I(2)+NI(3)*I(3)+NI(4)*I(4)
     * +NI(5)*I(5)+NI(6)*I(6)+NI(7)*I(7)+NI(8)*I(8)
     * +NI(9)*I(9)+NI(10)*I(10)+NI(11)*I(11)+NI(12)*I(12))
C
C NITROGEN REMOVED BY CROP(S)
C
      G(89)=X(1)*(X(50)+X(51)+X(52)+X(53)+X(54)+X(55)
     * +X(56)+X(57)+X(58)+X(59)+X(60)+X(61))
C
C PERCENTAGE OF NITROGEN REMOVED BY CROP(S)
C
      G(90)=G(89)/(NI(1)*I(1)+NI(2)*I(2)+NI(3)*I(3)*NI(4)*I(4)
     * +NI(5)*I(5)+NI(6)*I(6)+NI(7)*I(7)+NI(8)*I(8)
     * +NI(9)*I(9)+NI(10)*I(10)+NI(11)*I(11)+NI(12)*I(12))
C
C NITROGEN REMOVED IN SYSTEM
C
      G(91)=G(87)+G(89)
C
C PERCENT OF NITROGEN REMOVED BY SYSTEM
C
      G(92)=G(91)/(NI(1)*I(1)+NI(2)*I(2)+NI(3)*I(3)*NI(4)*I(4)
     * +NI(5)*I(5)+NI(6)*I(6)+NI(7)*I(7)+NI(8)*I(8)
     * +NI(9)*I(9)+NI(10)*I(10)+NI(11)*I(11)+NI(12)*I(12))
C
C MAXIMUM WEEKLY APPLICATION RATE
C
      G(93)=DMAX1(X(14),X(15),X(16),X(17),X(18),X(19),
     * X(20),X(21)+X(22)+X(23)+X(24)+X(25))/(X(1)*4.3)
      END
```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